# Doublet IR Focusing

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# Outline

- Motivation for considering doublet IR focusing.
- Preliminary design of an IR layout.
- Collision & Injection optics.
- Difficulties related to doublets.
- Summary & future study efforts.

# Doublet IR Assets

- Doublets can provide elliptical beams at the IP, such that $\sqrt{\beta_x^* \beta_y^*} \equiv \beta_0^*$ (round beams). Luminosity can then be enhanced via a smaller crossing angle in the plane of larger $\beta^*$.
- For ***symmetric*** doublet focusing $\beta_x(\max) = \beta_y(\max) \leq \beta_0(\max)$ of triplets & round beams at the IP.
- With half-crossing angle $\theta$ in a single plane, and short bunches, luminosity is reduced approximately by a factor:

$$R \approx \left[1 + \left( \sigma_l \theta \big/ \sigma_t^* \right)^2 \right]^{-1/2}$$

# Doublet IR (cont'd)

- For Nσ separation at the 1st parasitic crossing:

$$\theta / \sigma^* = \frac{N}{2\beta^*}$$

- With horizontal crossing (IP5) and elliptical beams $\beta_x^* > \beta_0^*$ $\Rightarrow$ $\theta_x < \theta_0$ for the same Nσ separation, and the luminosity reduction is not as large:

$$R_e = \left[1 + \left(\frac{\beta_0^*}{\beta_x^*}\right)^2 \cdot \left(\sigma\,\iota N / 2\beta_0^*\right)^2\right]^{-1/2} > R_0$$

# Doublets (still cont'd)

- Results for 10$\sigma$ separation at 1st PC, $\beta^*$(equivalent) = 0.25m, and $\sigma_s$ = 0.0755m:

  **<u>Round</u>** beams; with $\beta_0^* = 0.25\text{m} \Rightarrow \theta_0 = 224\ \mu\text{rad}$, then:

  $\boldsymbol{R_0 = 0.522}$.

  **<u>Elliptical</u>** beams; with $\sqrt{\beta_x^*\ \beta_y^*} = 0.25\text{m}$ & $\beta_x^* = 0.469\text{m}$ †

  $\Rightarrow \theta_x = 164\ \mu\text{rad}$, and:

  $\boldsymbol{R_e = 0.779}$

- Luminosity is enhanced using elliptical beams by ≈ 40% compared to the round beam result (*or*, the luminosity hit is only about 22% instead of 48%).

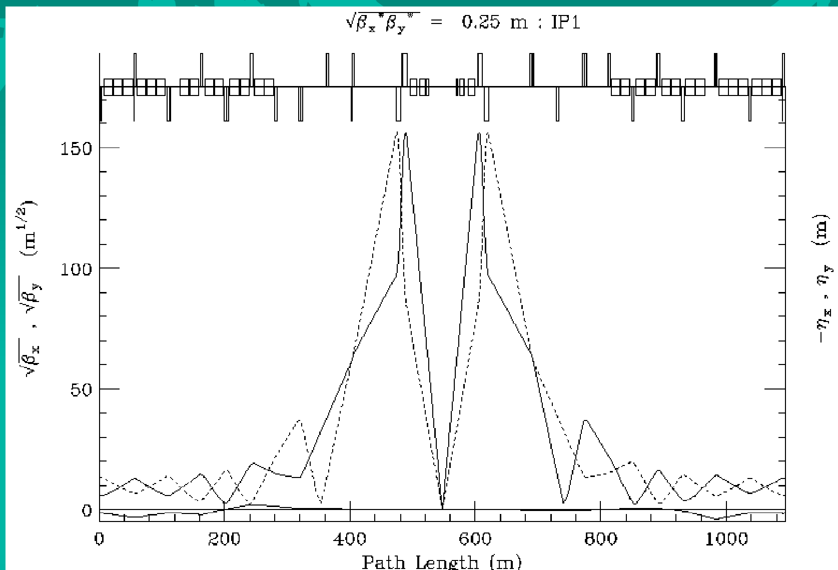
† [$\beta x^*$ = 0.469m is used in subsequent discussions]

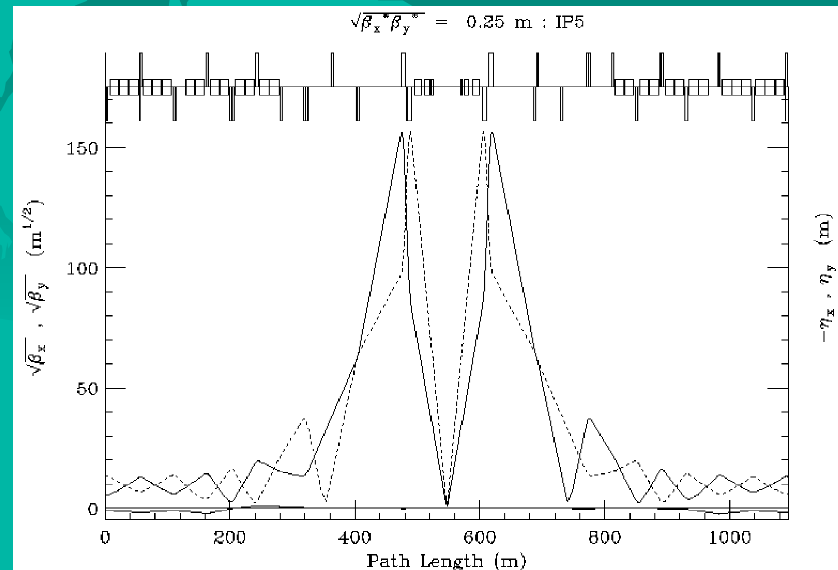
# Design Considerations

- With elliptical beams the doublets must be optically symmetric with respect to the IP to ensure $\beta_x(max) = \beta_y(max)$ and thereby conserve aperture.
- Symmetric doublets imply that 'dipoles first' is the only option — the beams must be in separate channels to experience equivalent focusing.
- Transition from the symmetric final focus optics to the optics of an intrinsically anti-symmetric lattice should be seamless.

# Symmetric Optics @ IP1 & IP5

(preliminary & still under construction)



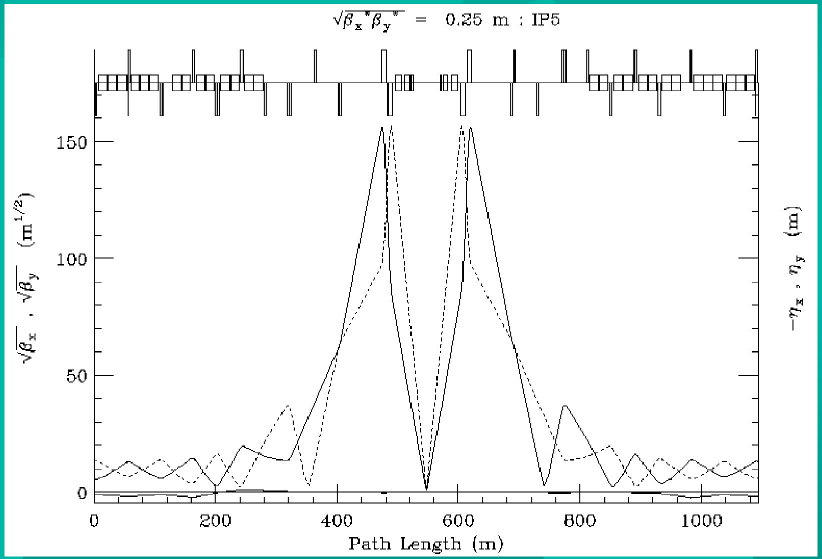




| | Symmetric Optics | | | | Antisymmetric Optics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Straight Section | | | | | | | Dispersion Suppression & Arc Cells | | | | | | |
| | Low-β Doublet | | | Symmetry Exchange | | | | | | | | | | |
| Magnet | Q1 | Q1T | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | QT11 | QT12 | QT13 |
| $L_{mag}$ (m) | 6.60 | 0.75 | 6.60 | 2.4 | 3.4 | 4.8 | 3.4<br>3.4 | 2.4 | 4.8 | 3.4<br>2.4 | 4.8 | 1.15 | 0.32 | 0.32 |
| G (T/m) | 200 | 150 | 200 | 160 | 160 | 160 | 160 | 160 | 200 | 200 | 200 | 110 | 110 | 110 |
| T (K) | 1.9 | 1.9 | 1.9 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |

# Collision Optics @ 7 TeV

| | Lmag (m) | Gradient (T/m) LS | RS |
|---|---|---|---|
| Q1 | 6.60 | -198.0 | -198.0 |
| Q1T | 0.75 | -110.3 | -110.3 |
| Q2 | 6.60 | 198.0 | 198.0 |
| Q3 | 2.4 | -65.4 | -65.4 |
| Q4 | 3.4 | -35.3 | +35.3 |
| Q5 | 4.8 | 6.0 | -6.0 |
| Q6 | 3.4+3.4 | -155.1 | 155.1 |
| Q7 | 2.4 | -44.5 | 44.5 |
| Q8 | 4.8 | 147.2 | -146.8 |
| Q9 | 3.4+2.4 | -200.0 | 200.0 |
| Q10 | 4.8 | 196.3 | -198.0 |
| QTL11 | 1.15 | -97.7 | 77.6 |
| QT12 | 0.32 | -26.9 | -43.6 |
| QT13 | 0.32 | 92.4 | -107.8 |

- $\sqrt{\beta x\ \beta y} = 0.25$ m
  $\beta x = 0.469$m & $\beta y = 0.133$m
- $\beta x(max) = \beta y(max) = 24.5$ km

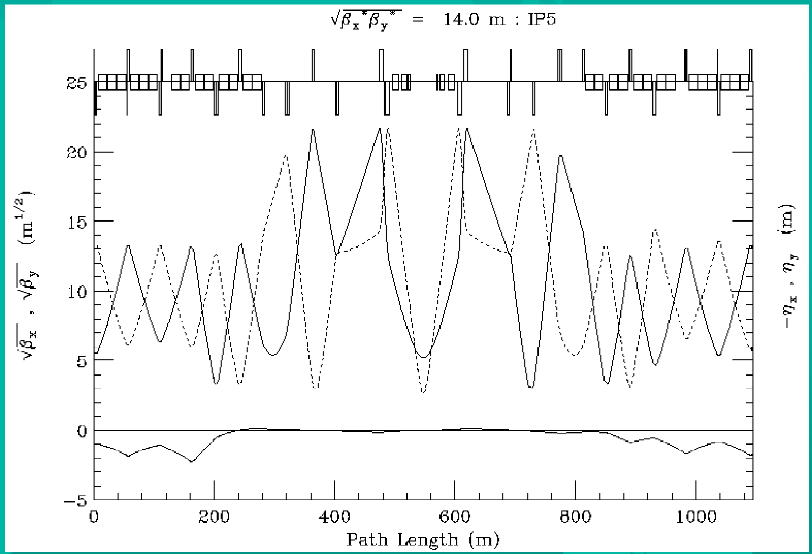



- 10σ horizontal separation at 1st parasitic for $\theta_{1/2}$ =164 μr

# Injection Optics @ 7 TeV

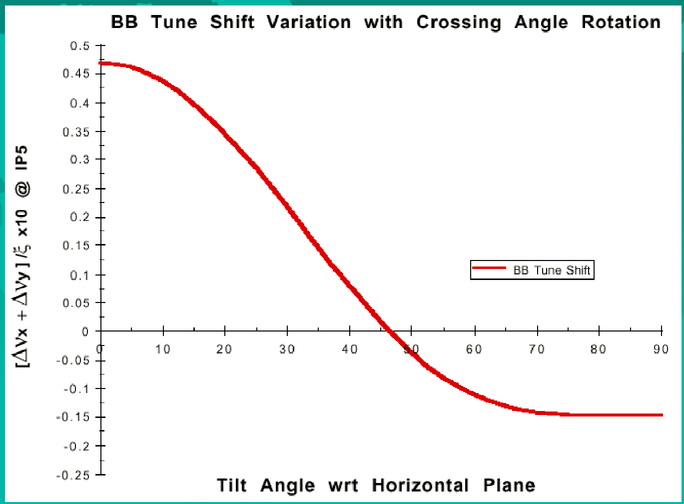
| | Lmag (m) | Gradient (T/m) LS | RS |
|---|---|---|---|
| Q1 | 6.60 | -182.3 | -182.3 |
| Q1T | 0.75 | -149.4 | -149.4 |
| Q2 | 6.60 | 182.3 | 182.3 |
| Q3 | 2.4 | -43.7 | -43.7 |
| Q4 | 3.4 | -158.2 | +158.2 |
| Q5 | 4.8 | 135.6 | -135.6 |
| Q6 | 3.4+3.4 | -100.9 | 100.9 |
| Q7 | 3.4 | -86.1 | 86.1 |
| Q8 | 4.8 | 193.2 | -197.4 |
| Q9 | 3.4+2.4 | -164.2 | 177.0 |
| Q10 | 4.8 | 174.8 | -174.3 |
| QTL11 | 1.15 | -7.0 | 50.7 |
| QT12 | 0.32 | -87.0 | +73.1 |
| QT13 | 0.32 | 17.6 | +46.4 |

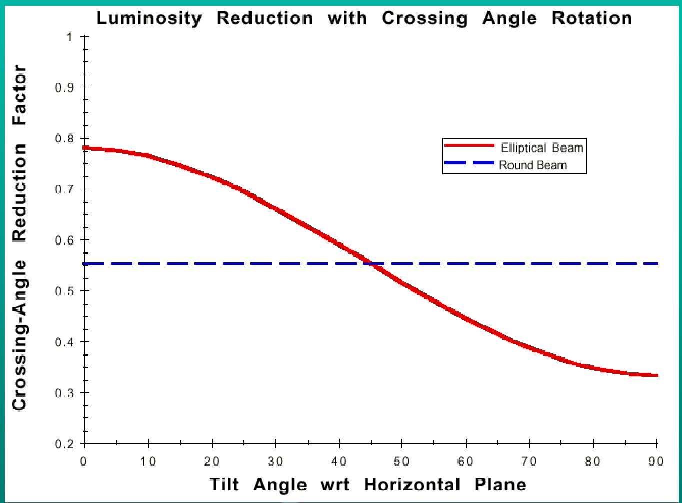
- $\sqrt{\beta x\ \beta y} = 14.0$ m
  $\beta x = 27.25$m & $\beta y = 7.19$ m
- $\beta x(max) = \beta y(max) = 465$ m




- 10σ horizontal separation at 1st parasitic for $\theta_{1/2}$ =21.5 μr

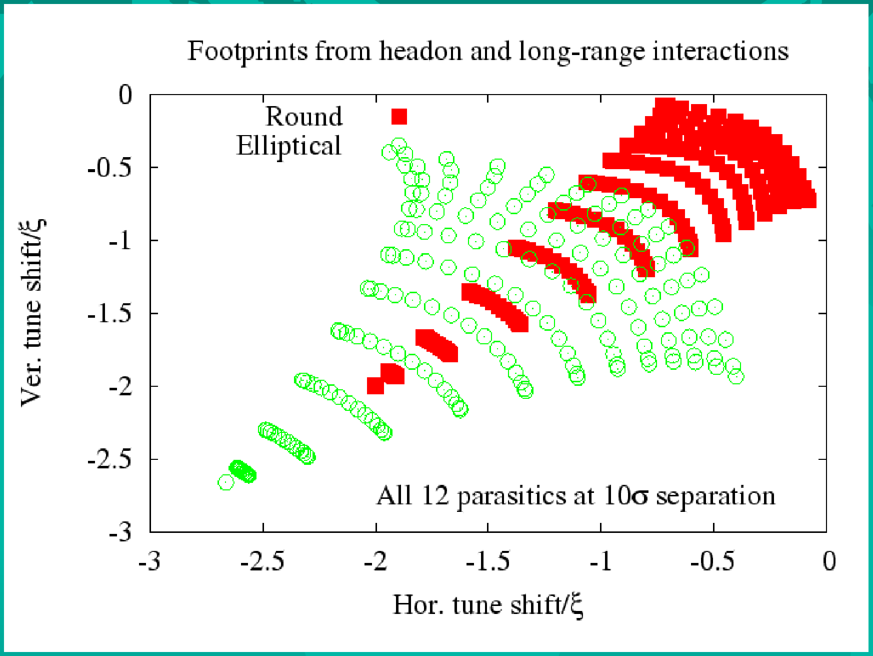
# Elliptical Beam Long Range Tune Shifts




- Unlike triplets & round beams, elliptical long range beam-beam tune shifts do not cancel.
- Rotating the crossing angle plane reduces the tune shifts, but, *complete* cancellation, which occurs for a tilt of $\varphi = 45^{o}$, leaves zero luminosity benefits, i.e; $Re(\varphi=45^{o}) = R_0 = 0.522$
- Increasing separation beyond the nominal $10\sigma$ helps until reaching the luminosity break-even point: $Re(18.75\sigma) = R_0\,(10\sigma) = 0.522$ The BB tune shift is reduced by a factor of 3.35 to $0.0140\zeta$ — still much larger than for round beams.

# Tune Shifts (cont'd)




Courtesy of T. Sen 10.02.05

- Tune footprints extending to 6σ have been calculated for round & elliptical beams assuming 12 parasitics per IR.
- The elliptical beam footprint is significantly larger than that of round beams.

† Long range tune shifts are a concern that needs to be addressed. Avenues to explore might include a D0 trim to separate beams earlier, or re-examine wire compensation schemes, or .......

# Summary & Future Studies

- For the 'dipole first' upgrade option, symmetric doublet focusing has the attractive potential to enhance luminosity via colliding elliptical beams at the IP.
- Recently it was realized that the long-range beam-beam tune shifts are considerably larger for elliptical beams than for round beams and are a concern for the doublet approach.
- The highest priority for near-term studies must be to evaluate the importance of the large tune shifts and explore means to mitigate them. At that point it then becomes sensible to refine details of the doublet IR optics design.

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